NTSB National Transportation Safety Board

Office of Research and Engineering

Finite Element Analysis

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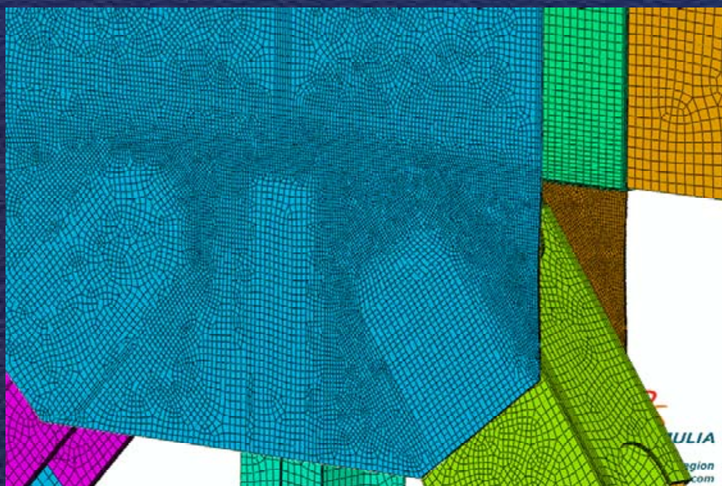
Presentations

1. Bridge description and collapse
2. Construction activities on bridge at time of collapse
3. Gusset plate inadequacy
4. Finite Element Analysis
5. Design and review process
6. Bridge load rating and bridge load analysis
7. Bridge inspections
8. Gusset plate inspections

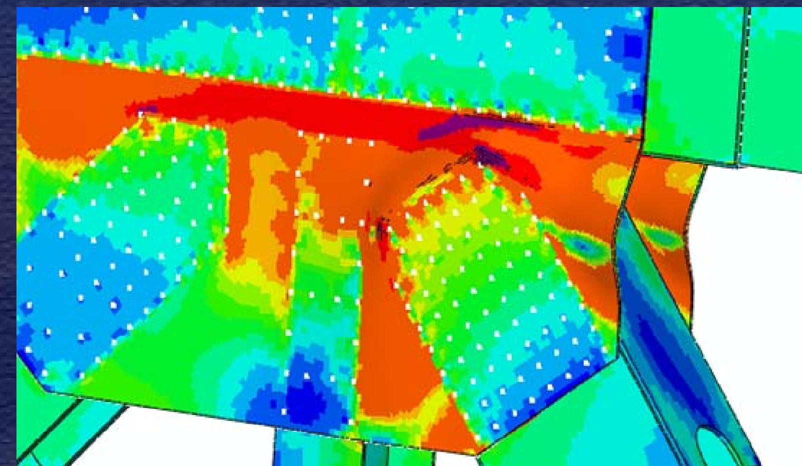
Overview

- Finite Element Analysis approach
- Models and inputs
- Loads in the U10 gusset plates at the time of the accident
- Stress levels in U10 gusset plates over the life of the bridge
- Failure initiation mechanism
- Factors that did not contribute to collapse

Finite Element Analysis



Computer model
of interconnected
simple elements



Computer-calculated
deformation and
stress in the model

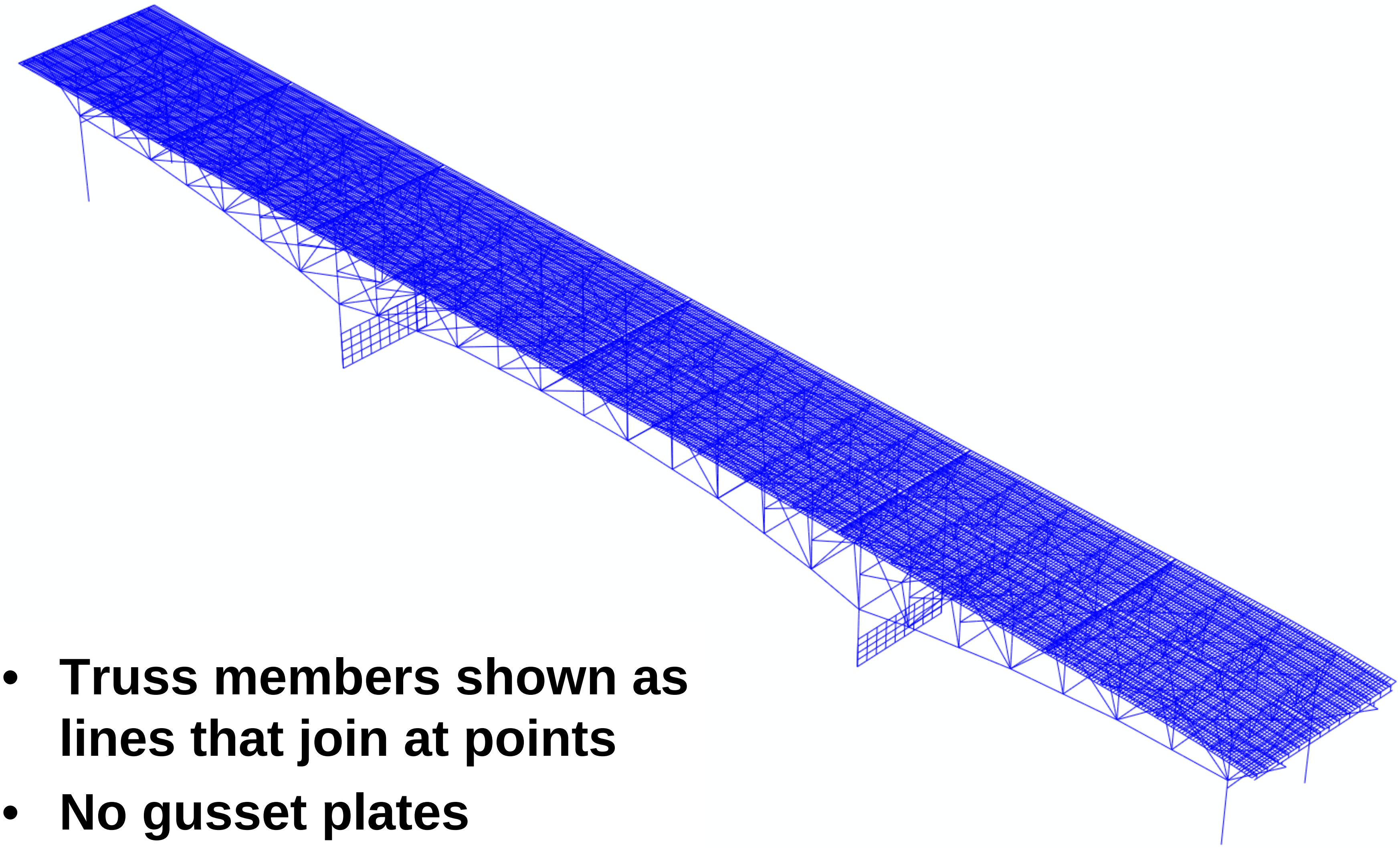
Finite Element Analysis Approach

- Guided by physical observations of collapsed structure
- Finite Element Analysis used to
  - Evaluate effects of loads on the bridge
  - Calculate stresses and investigate failure mechanisms
  - Evaluate and reinforce findings drawn from the physical observations
  - Provide new findings
- Focused on U10 and L11 nodes

Finite Element Analysis Team

- FHWA Turner-Fairbank Highway Research Center
  - Global model of the entire bridge
  - Detailed models of U10 and L11 nodes
- State University of New York at Stony Brook (SUNY) and Simulia (ABAQUS software developer)
  - Detailed models of U10 and L11 nodes
- Review and input from parties
- Review by Sandia National Laboratories

Global Model of Bridge



- Truss members shown as lines that join at points
- No gusset plates

FHWA Global Model

- Calculate forces in members under various applied loading conditions
- Transfer the applied loads and any deformations of the truss to the detailed models of U10 and L11
- Showed bridge design (other than gusset plates) was consistent with AASHO specifications

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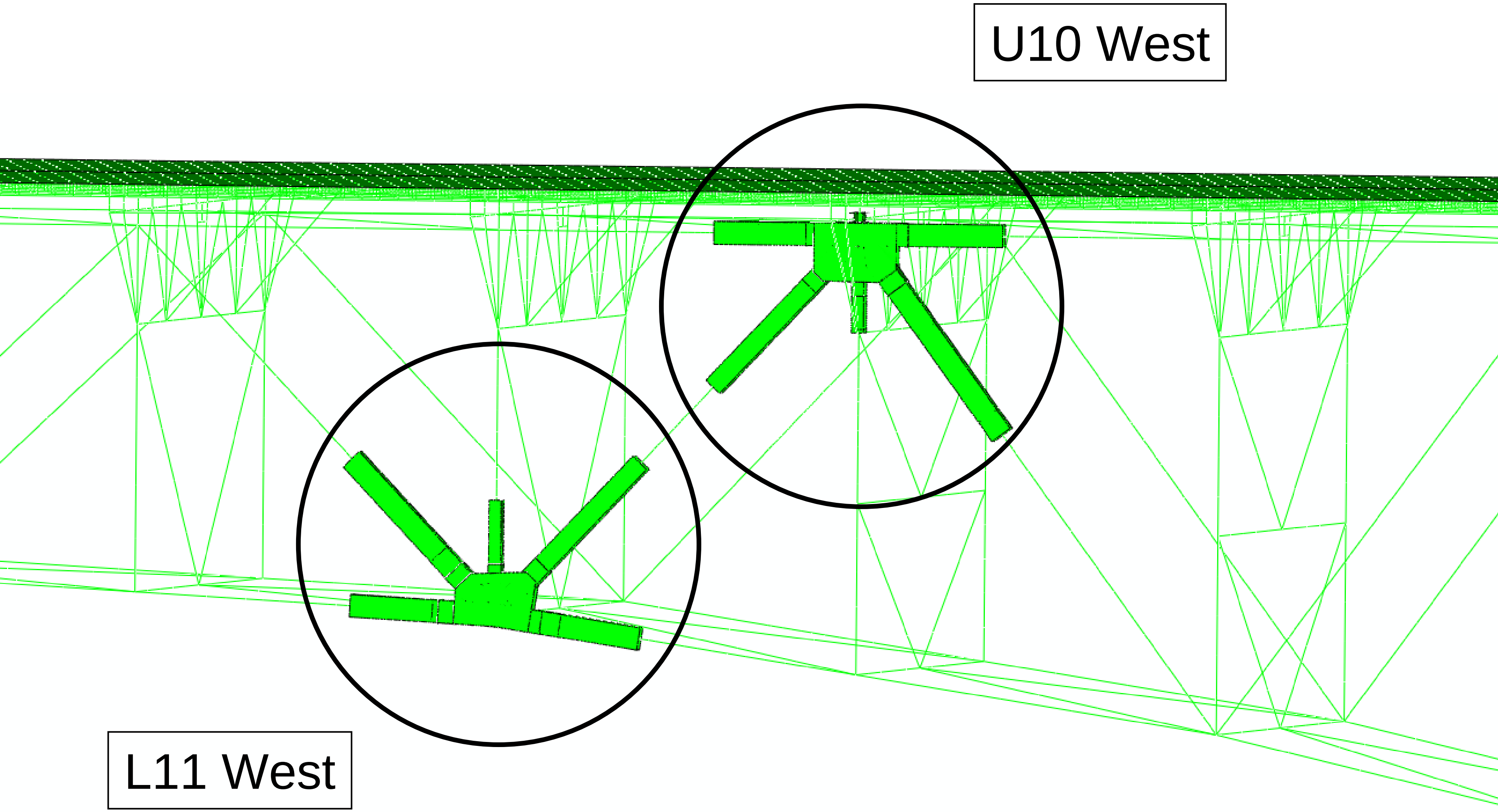
Detailed Models



Detailed Models

- Calculate stresses and deformations in the gusset plates directly
- Integration within the global model provides for accurate transfer of loads and deformation from the truss
- Integration also allows for feedback from the detailed model to the global model
- Failure initiation mechanism that was identified requires this feedback loop to be accurately captured

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Inputs to Computer Model

- Design drawings and shop drawings
- Weight of steel
- Weight of concrete
  - Original design
  - 1977 increase in deck thickness
  - 1998 modifications to barriers
  - 2007 deck removed in southbound lanes
- Loads applied sequentially to simulate the history of changes to the bridge

Inputs to Computer Model

- Tension tests on U10 gusset plate samples used for material property input beyond yield stress
- Tension tests on main truss members surrounding U10 and U10′, and on samples from floor truss 10
- U10 gusset plate Charpy V-notch tests
- U10 gusset plate fracture toughness tests
- U10 and L11 gusset plate hardness tests
- No significant deficiencies were found in any of the material properties measured

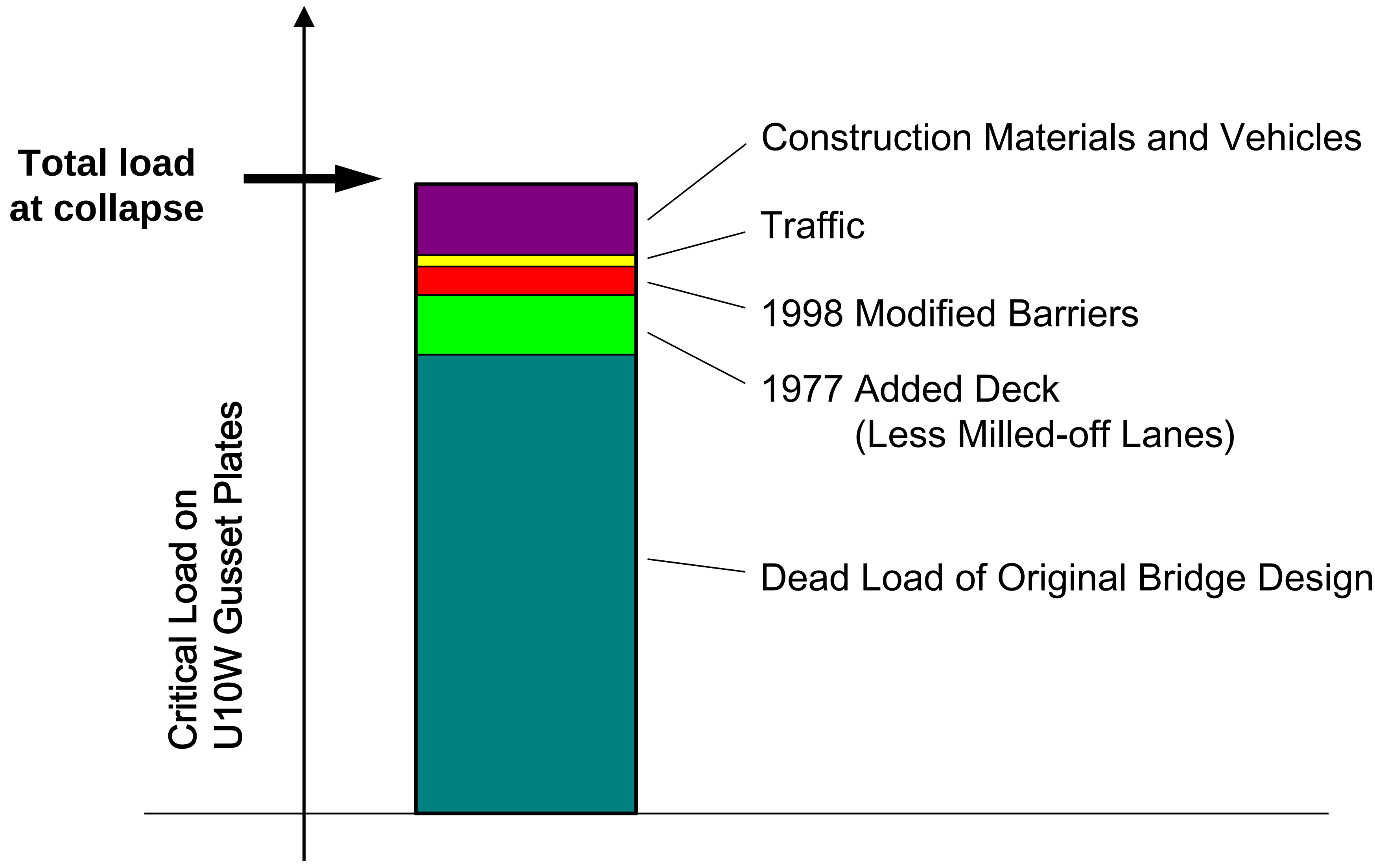
Inputs to Computer Model

- Bearing conditions calibrated against 1999 strain-gage data
- Bowing distortion of U10 gusset plates
- Section loss from corrosion of L11 gusset plates
- Weights and positions of traffic and construction materials and vehicles
- Ambient temperature
- Differential temperature east to west

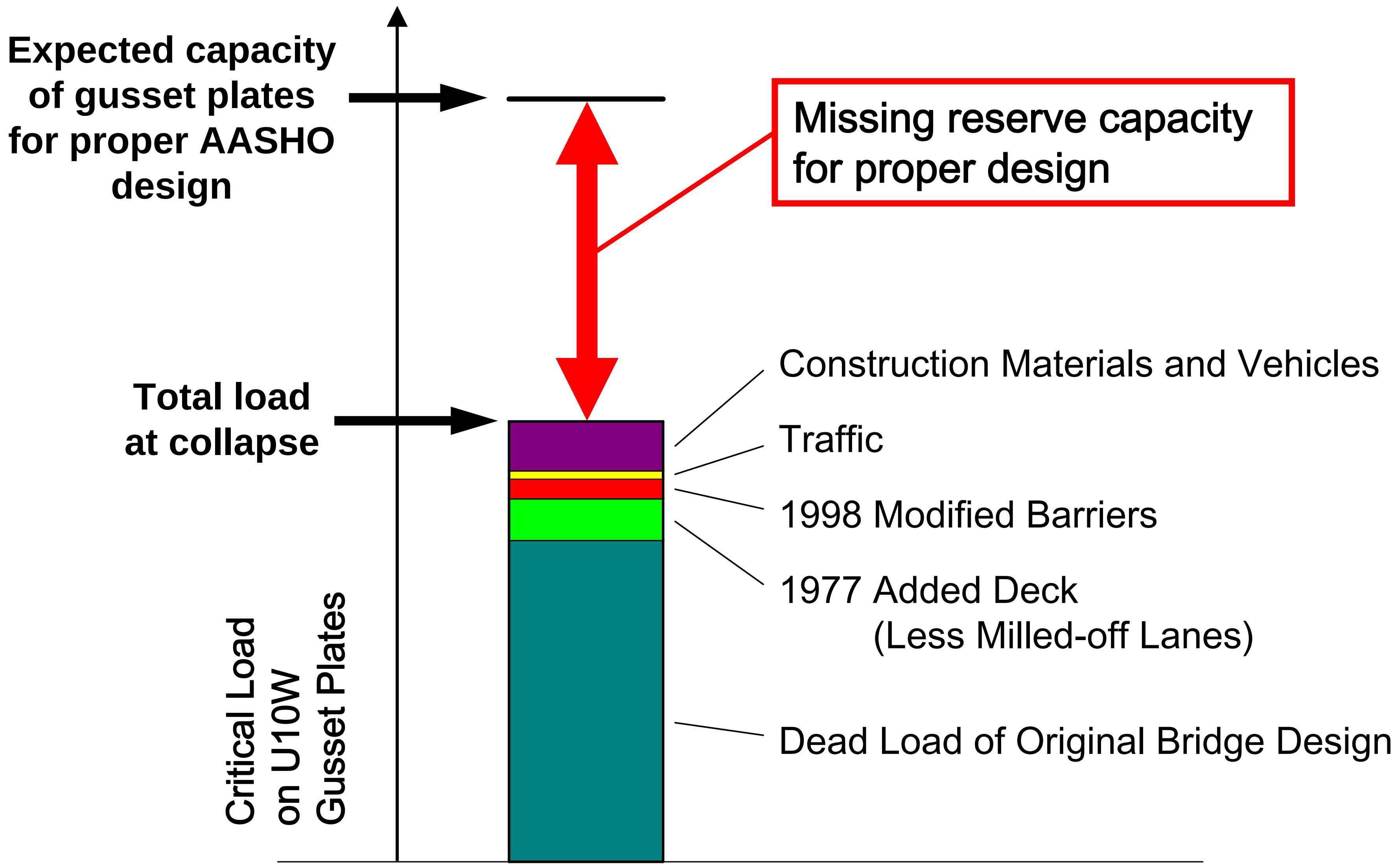
Results from Computer Model

- Contribution of loads over the history of the bridge
- Stresses in the gusset plates at U10W
- Failure initiation mechanism
- Bowing of gusset plates at U10W
- Comparison of U10W and U10E

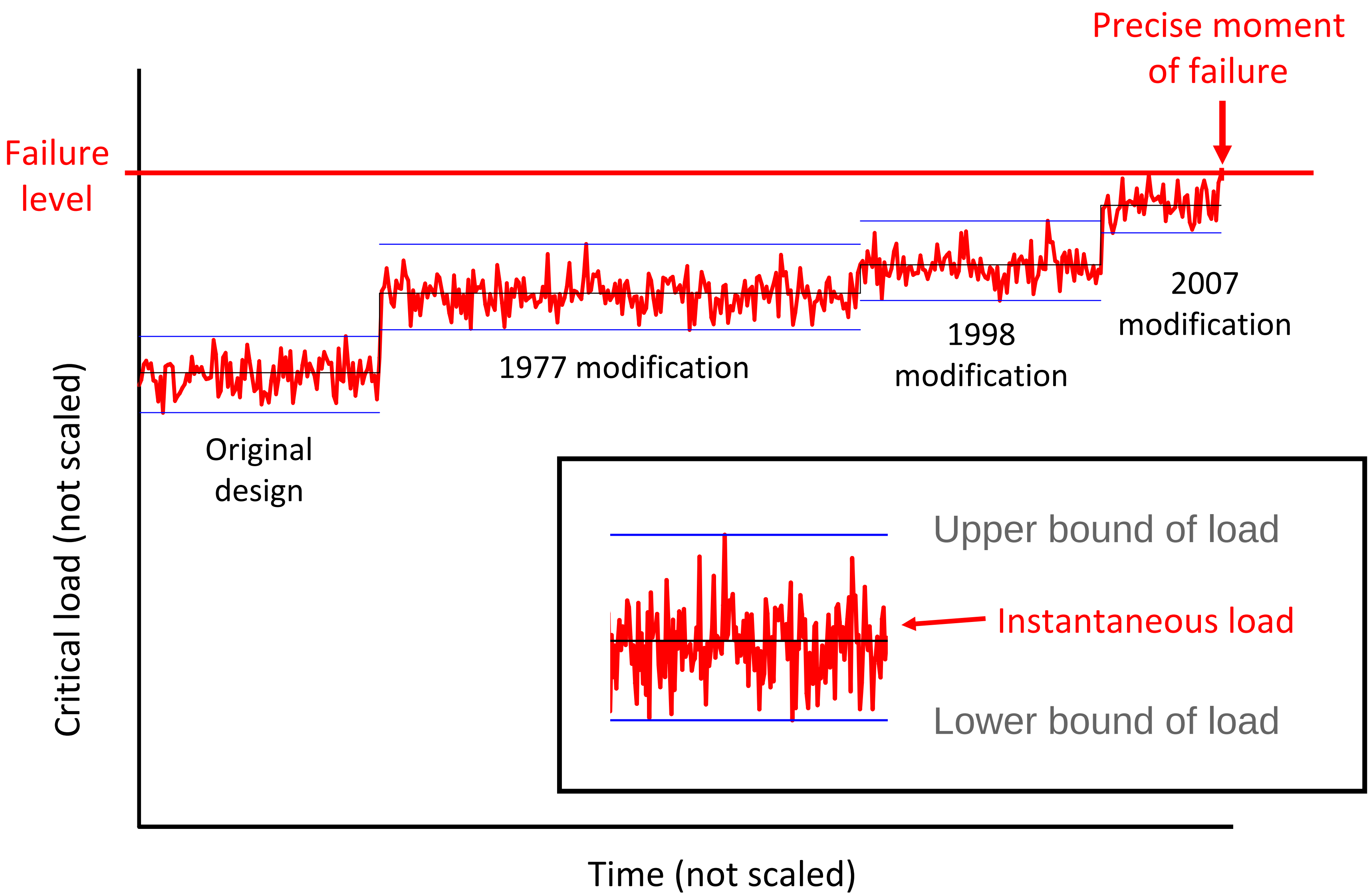
Increasing Loads on U10W Gusset Plate



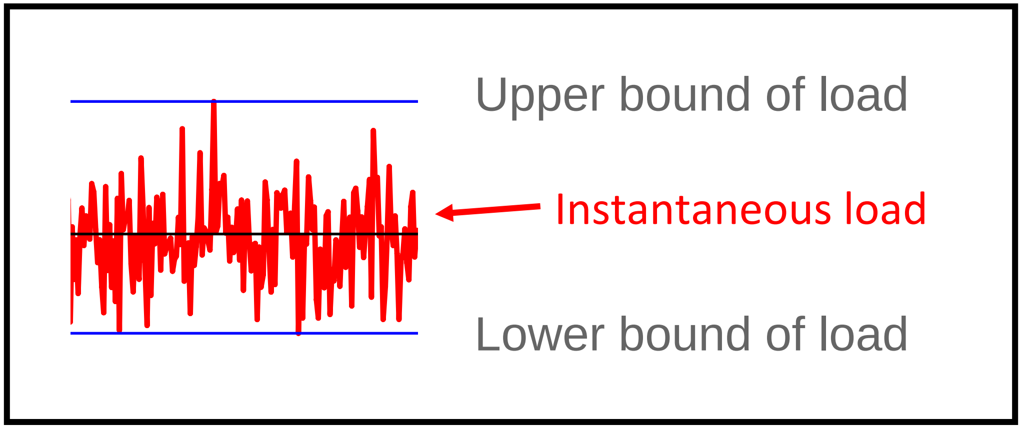
Increasing Loads on U10W Gusset Plate



Crossing the Threshold of Failure



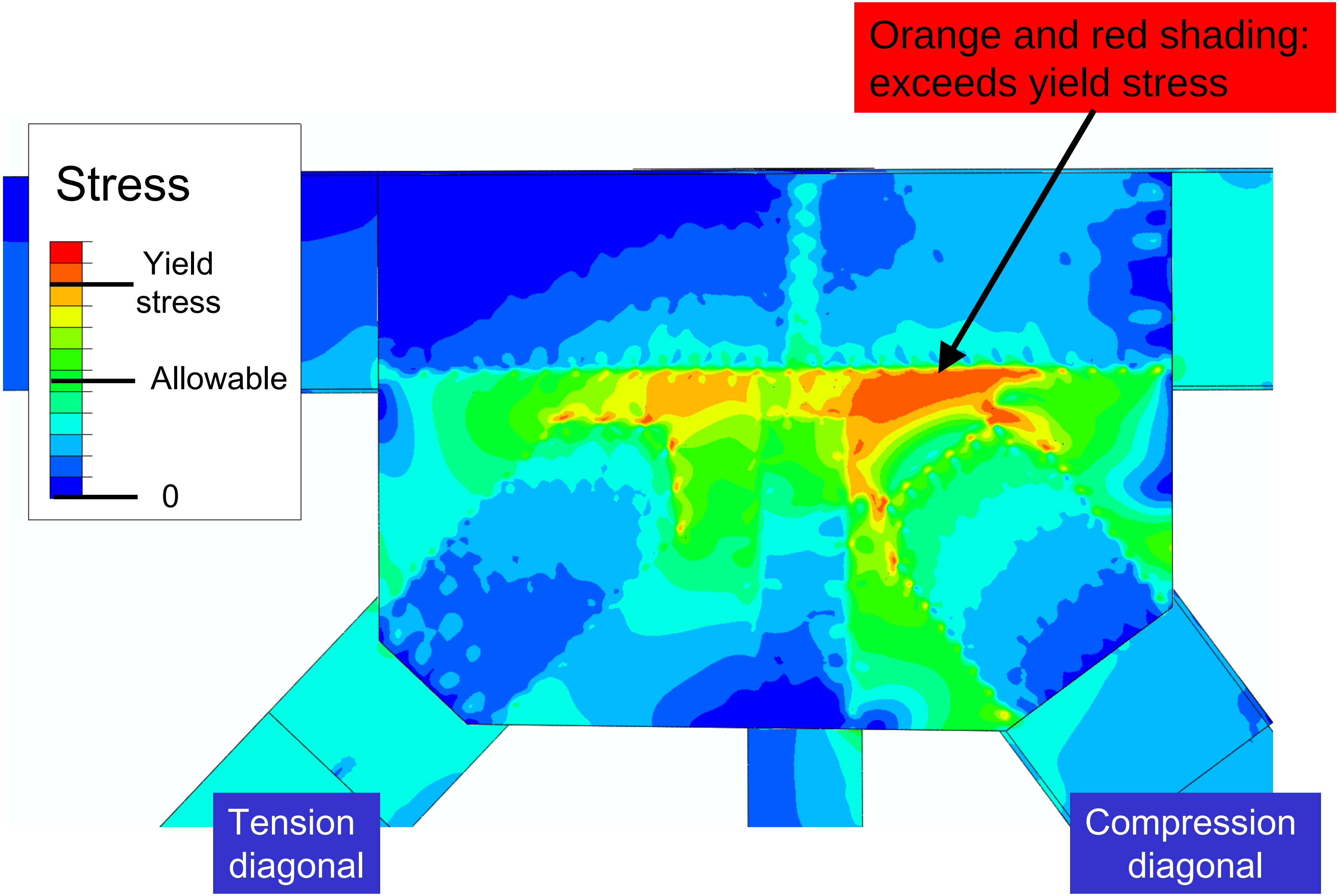
Instantaneous Loads are Variable



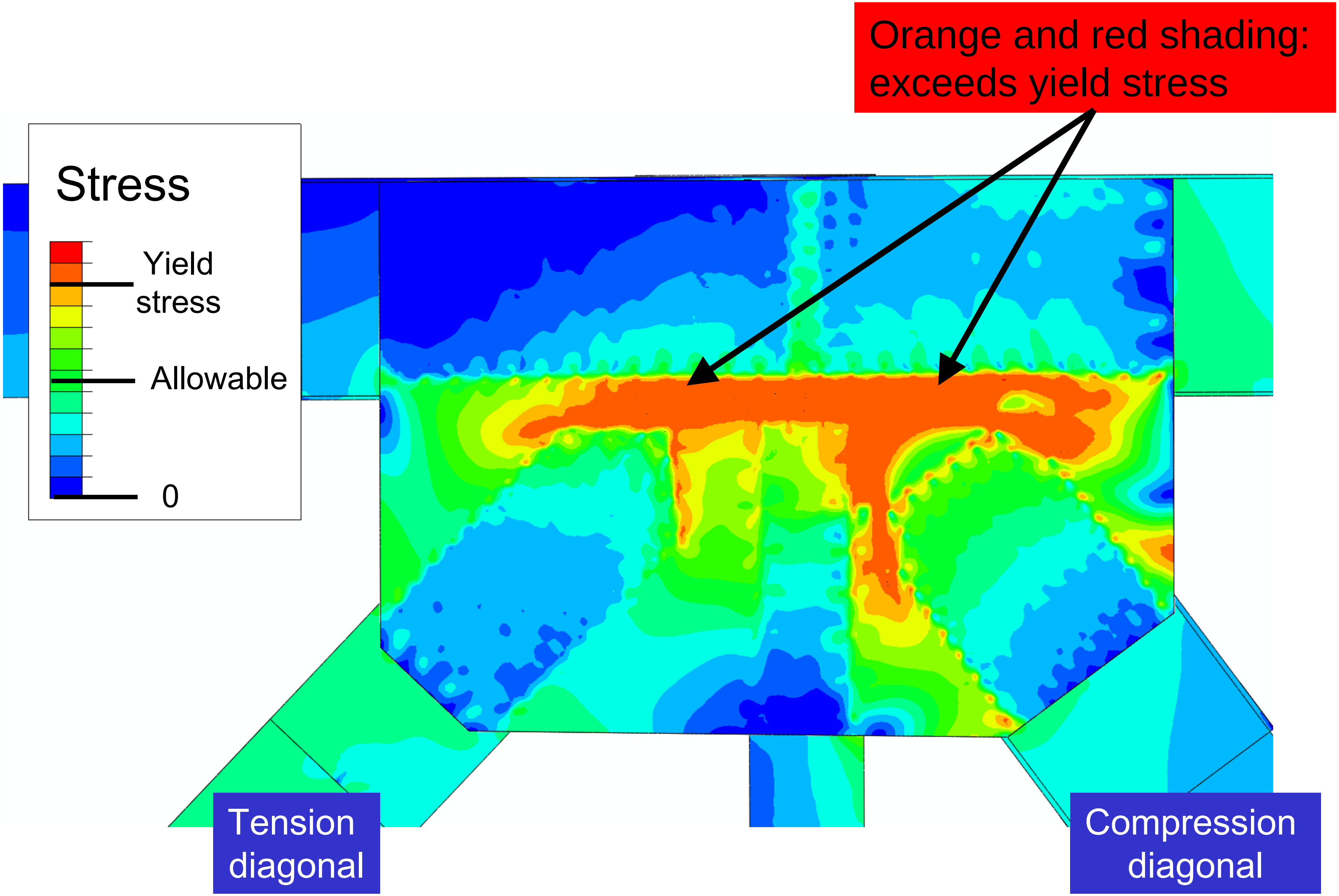
Some of the many sources of variability at the time of the accident

- Traffic
    - Amount
    - Position
    - Motion
- Weather
    - Wind
    - Temperature
- Construction Activity
    - Amount
    - Position
    - Motion

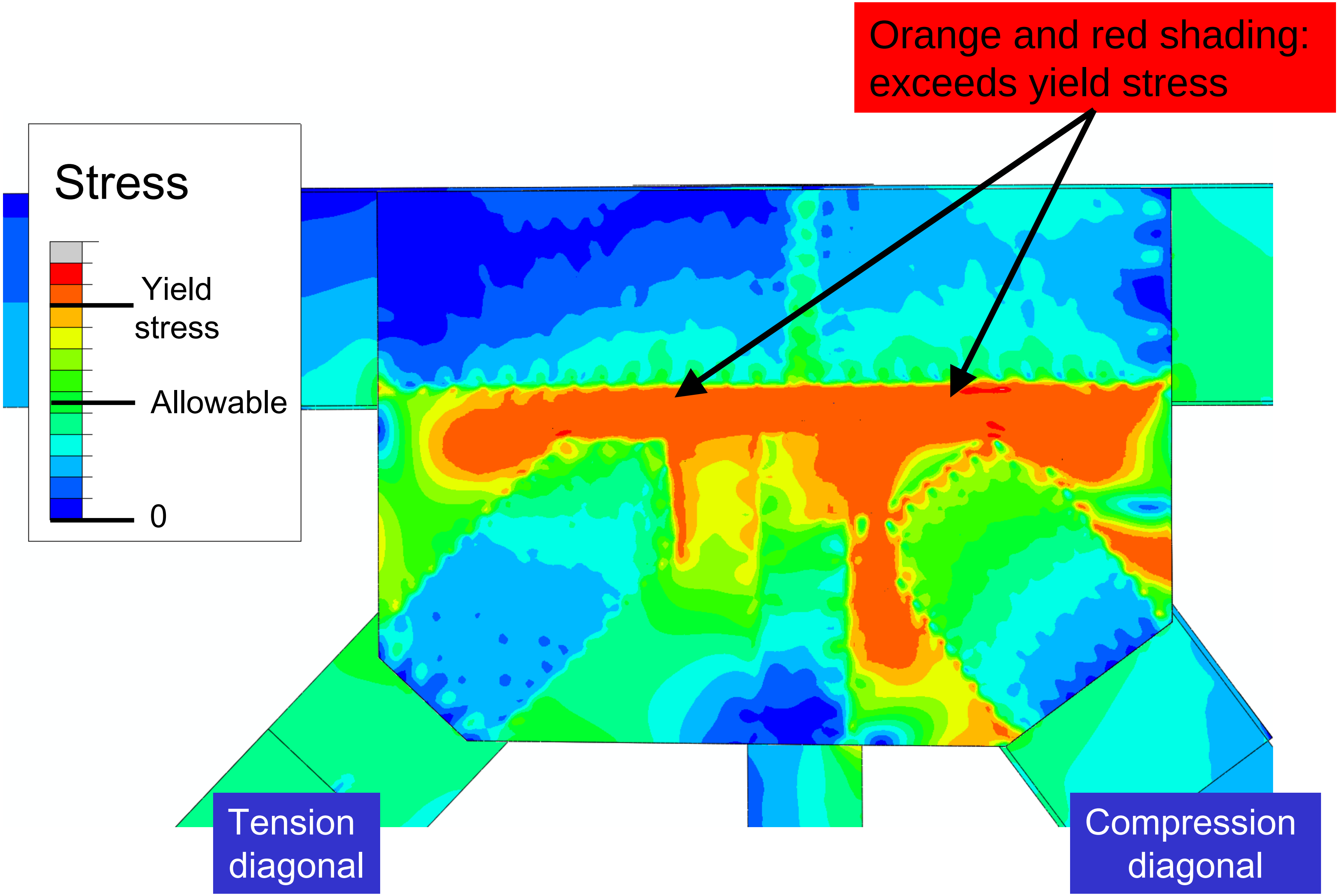
Dead Load of Original 1967 Bridge



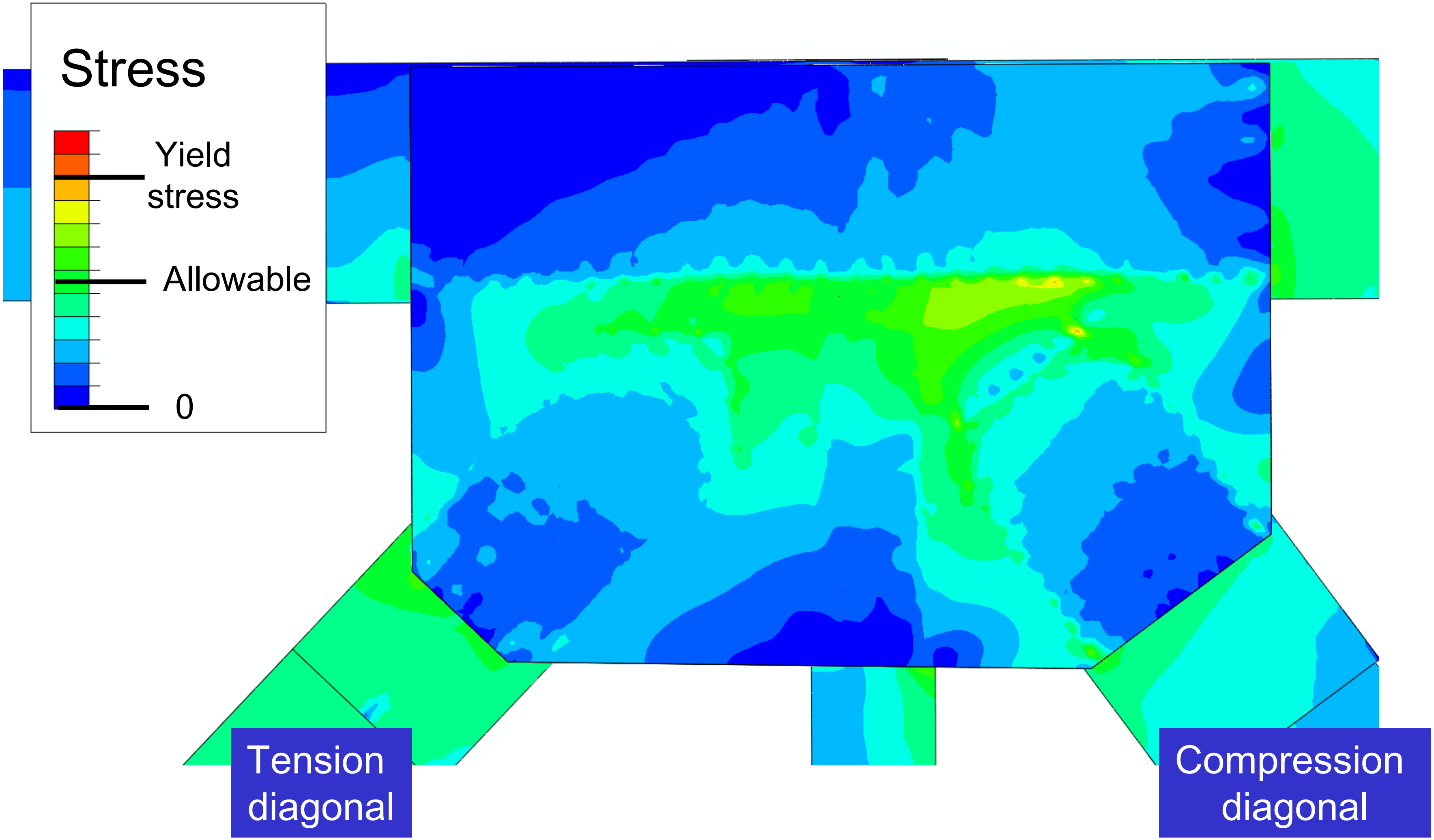
After 1977 and 1998 Modifications



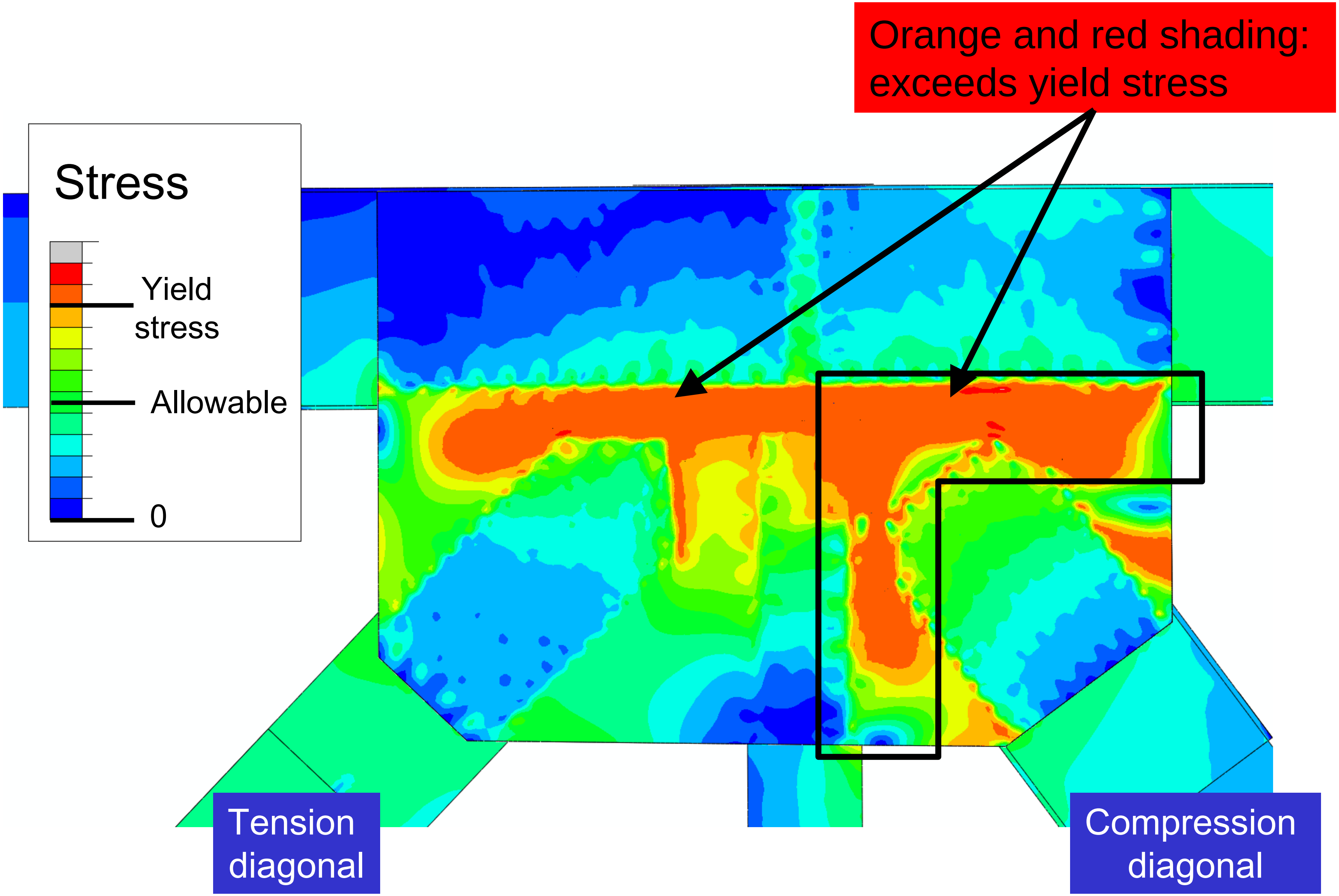
Loads at Time of Accident



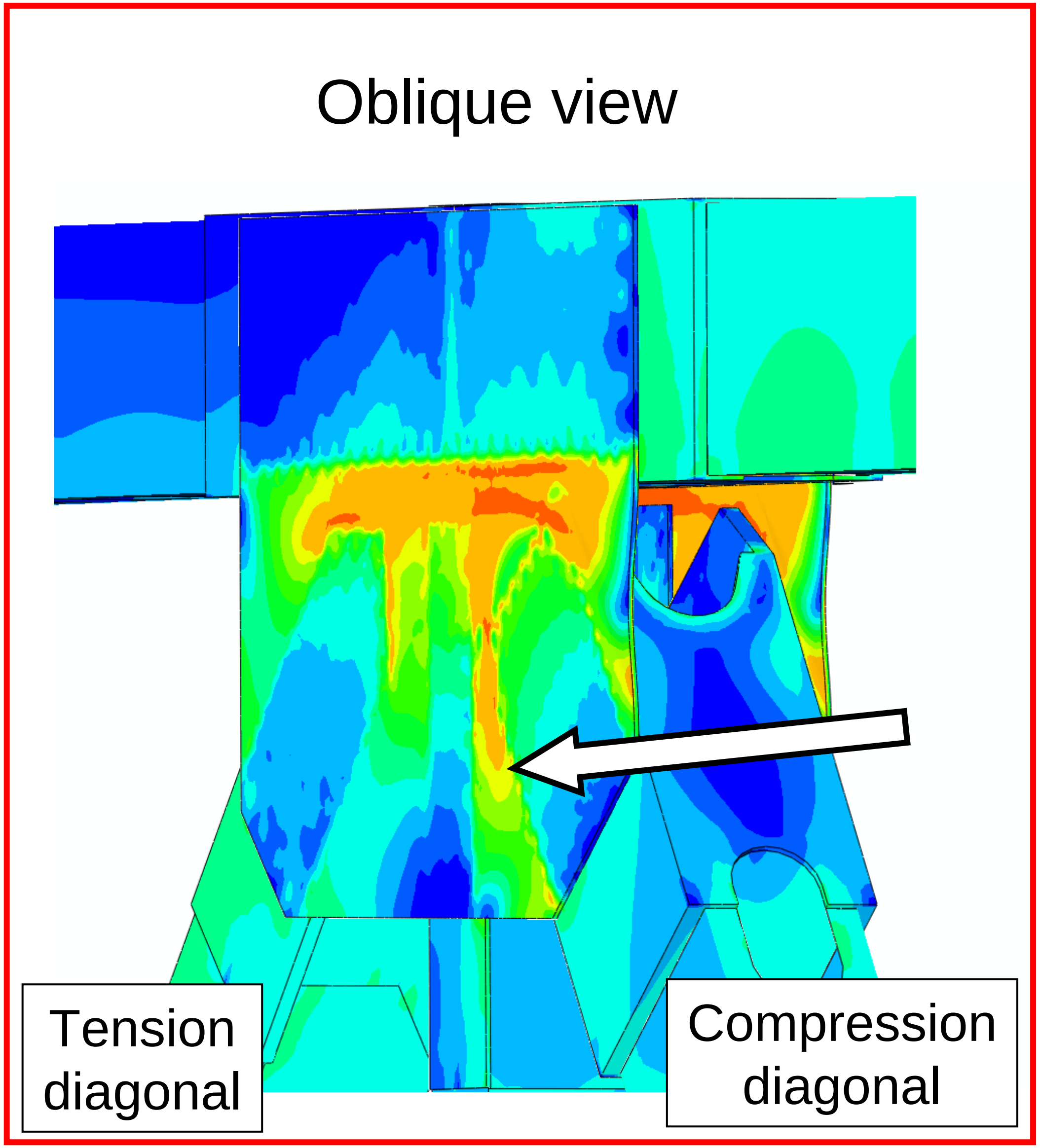
Accident Loads on 1-Inch-Thick Gusset Plates

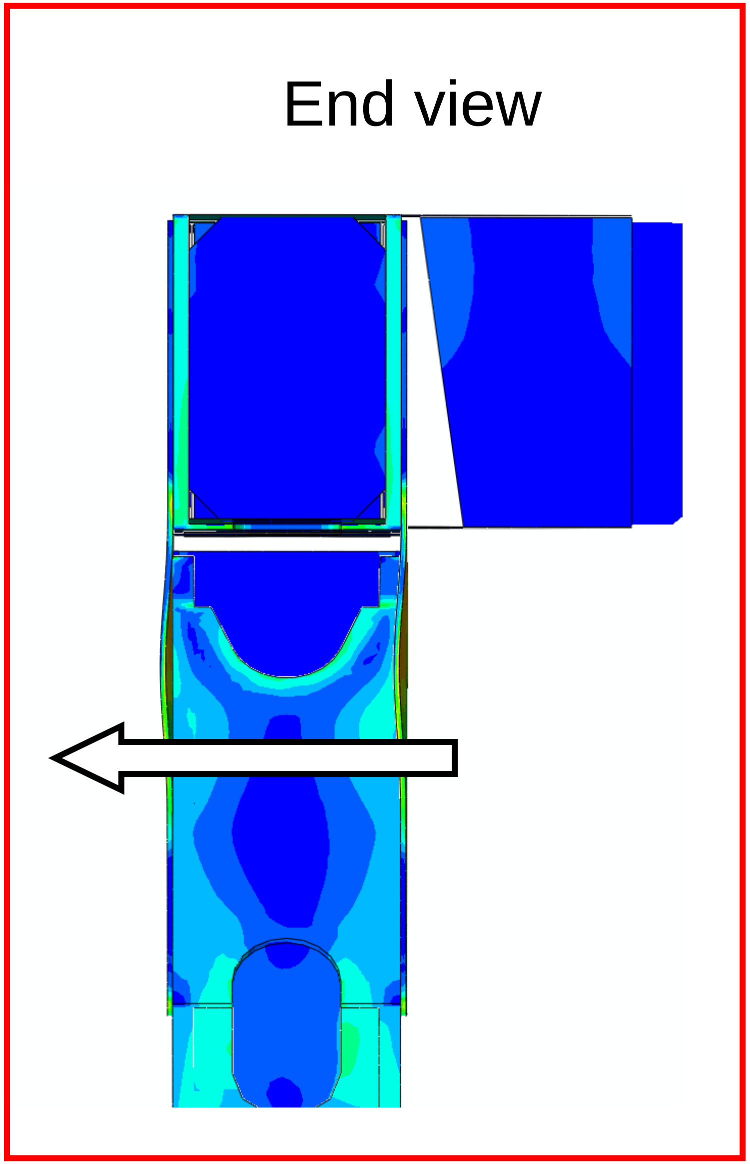


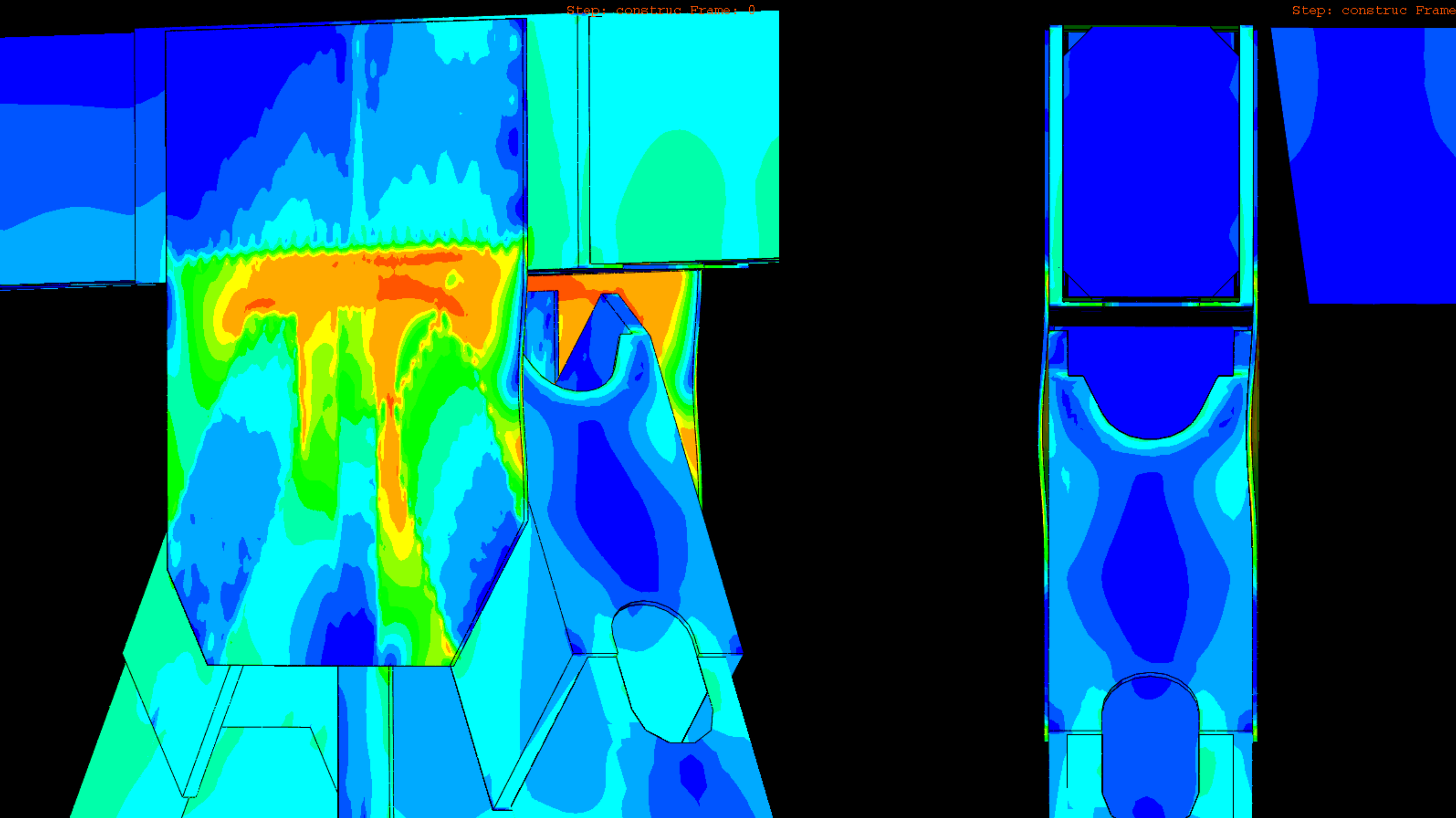
Loads at Time of Accident



Simulation – Failure Initiation



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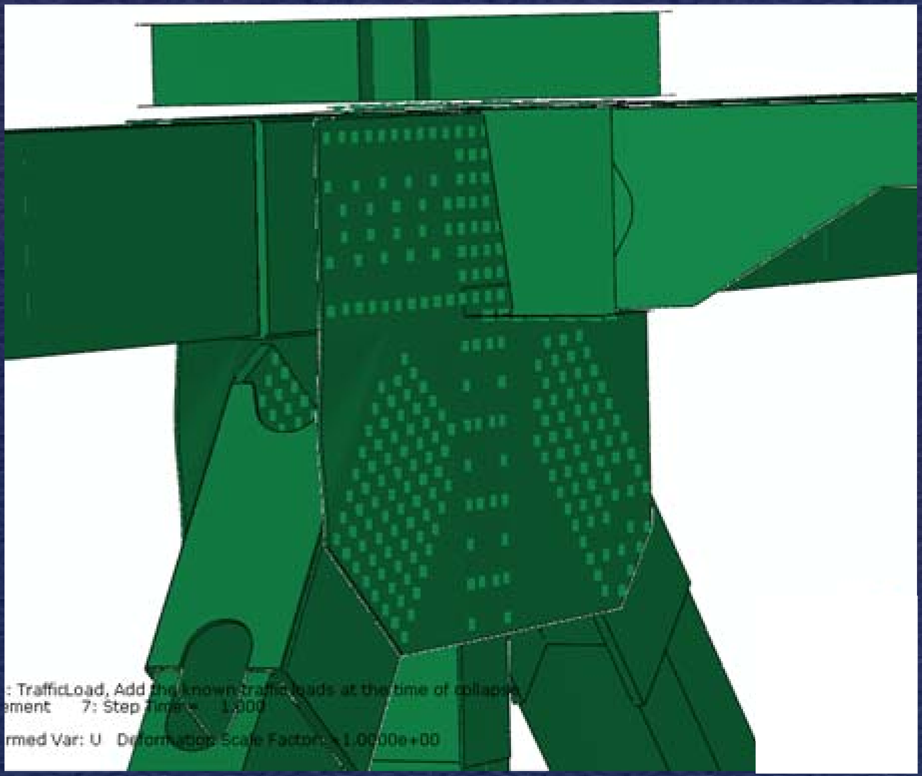
Bowed U10 Gusset Plates

2003 Photo

Computer Model

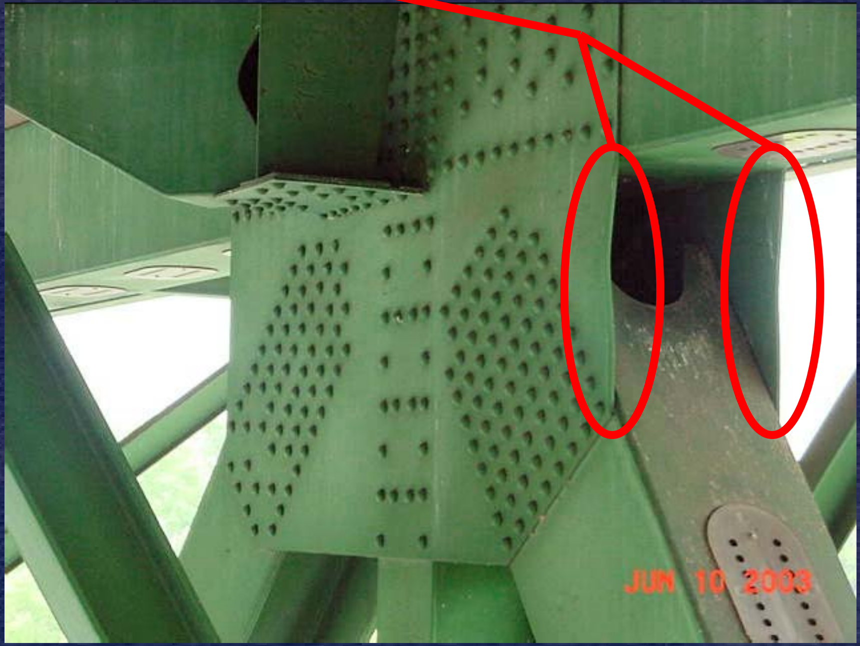


Bowed Gusset Plates

- Reduced load necessary to trigger instability
- Upper end of the compression diagonal shifted to the outside of the bridge, consistent with physical observations
- A symptom of the inadequate capacity of the U10 gusset plates
- Distortion such as bowing should be identified and evaluated

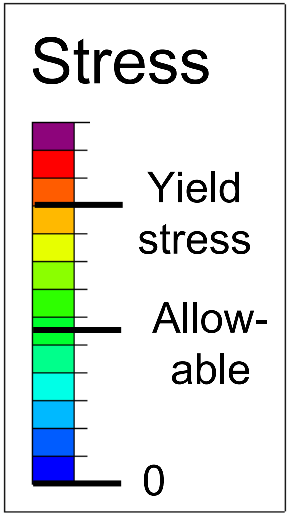
Edge Stiffeners on U10 Gusset Plate

Areas where stiffeners would be installed

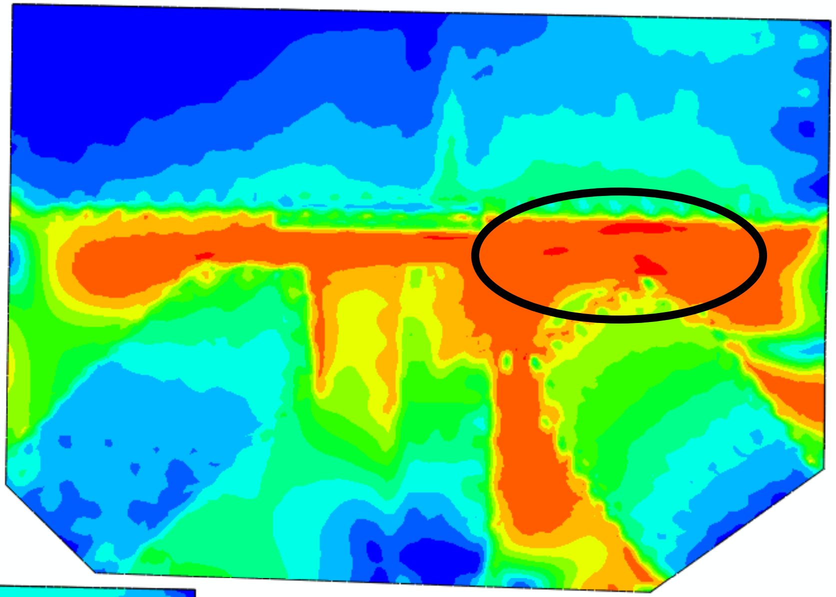


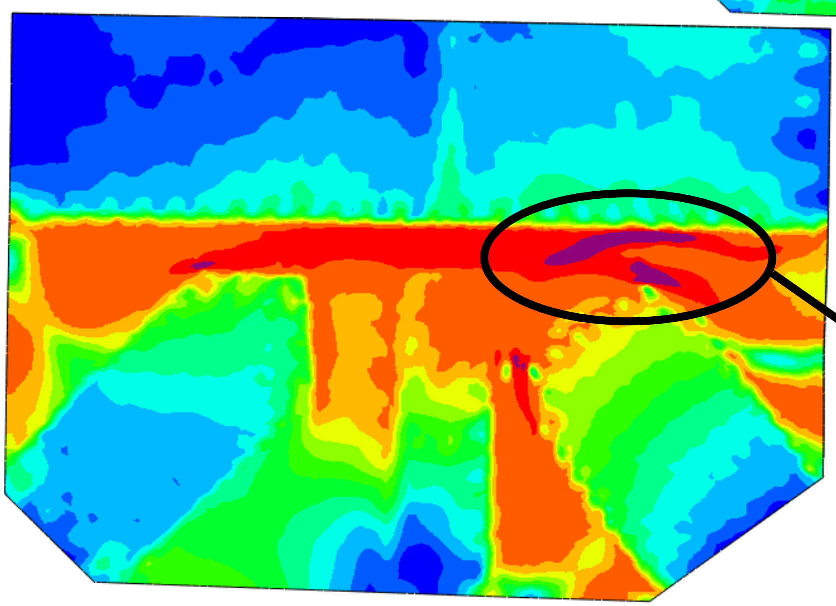
Edge stiffeners would not prevent gusset plate yielding

U10 West and U10 East



U10 East





U10 West

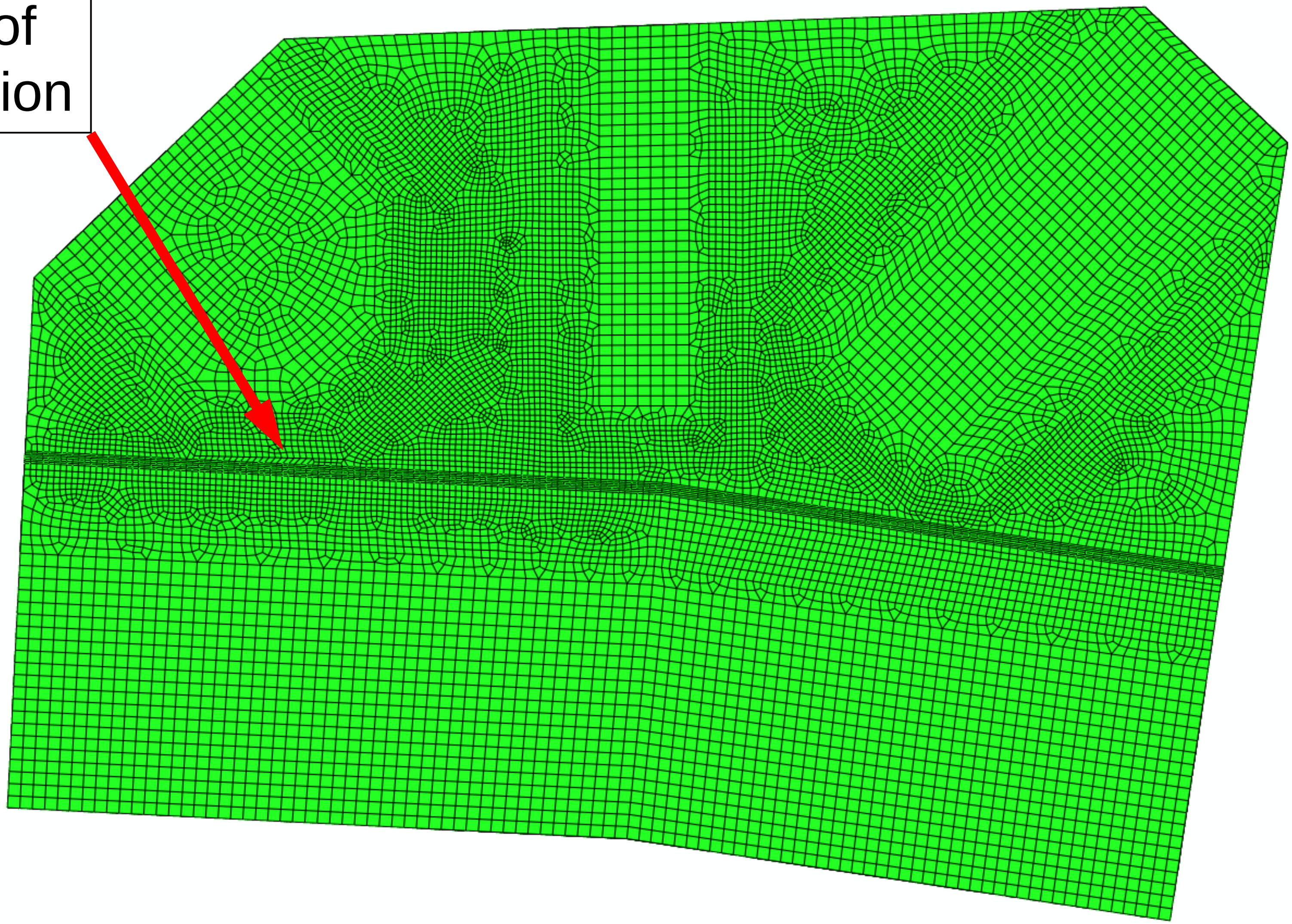
Has higher stress at the time of the accident

Factors that Did Not Contribute

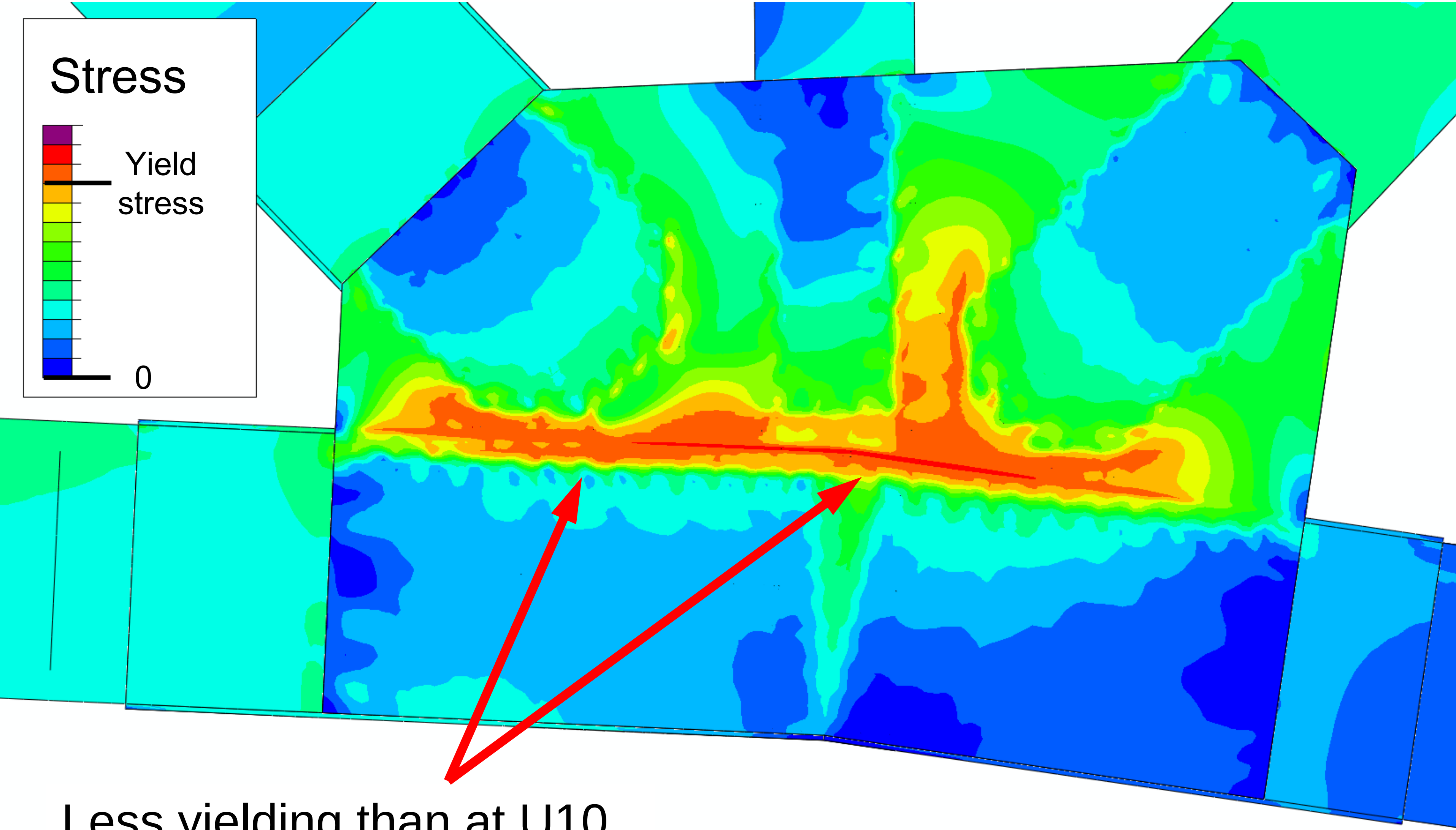
- Corrosion of the gusset plates at the L11 nodes
- Stress from thermal expansion resulting from changes in temperature on the day of the accident

Model of L11 with Corrosion

Band of corrosion



L11W with Corrosion – Accident Conditions



Less yielding than at U10

L11 Gusset Plates with Corrosion

- Did not affect loads at U10 West
- Did not alter load that triggered instability at U10 West
- Able to support much higher applied loads than those that triggered instability at U10 West

Temperature Effects

- Temperature increased from 73 °F to 92 °F
- Differential temperature in main trusses
  - East truss calculated to be about 1 °F above ambient
  - West truss calculated to be about 11 °F above ambient
- Thermal expansion under uniform temperature increase or differential temperature increase
  - Reduced the force in the U10W compression diagonal, which drives the instability
- Assessment: Thermal expansion of structure did not play a significant role in collapse

Summary

- Collapse began at node U10W when highly stressed gusset plates were unable to prevent unstable lateral shift of upper end of highly loaded compression diagonal
- Gusset plates meeting AASHO specifications would have safely supported loads on bridge at time of accident
- Bowed gusset plates reduced load necessary to trigger instability and resulted in lateral shift to outside of bridge, consistent with physical observations

Summary – Factors That Did Not Contribute

- Corrosion of gusset plates at the L11 nodes did not contribute to the collapse
- Thermal expansion under uniform temperature change or differential temperature change did not play a significant role in collapse

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